The Astronomical Journal, 132:1989–1994, 2006 November

SPITZER SPACE TELESCOPE OBSERVATIONS OF VAR HER 04: POSSIBLE DETECTION OF DUST FORMATION IN A SUPEROUTBURSTING TREMENDOUS OUTBURST AMPLITUDE DWARF NOVA

David R. Ciardi
Michelson Science Center, California Institute of Technology, 770 South Wilson Avenue, MS 100-22, Pasadena, CA 91125; ciardi@ipac.caltech.edu

Stefanie Wachter and D. W. Hoard
Spitzer Science Center, California Institute of Technology, 1200 East California Avenue, MS 220-6, Pasadena, CA 91125

Steve B. Howell
WIYN Observatory and NOAO, P.O. Box 26732, 950 North Cherry Avenue, Tucson, AZ 85719

and

Gerard T. van Belle
Michelson Science Center, California Institute of Technology, 770 South Wilson Avenue, MS 100-22, Pasadena, CA 91125
Received 2006 June 2; accepted 2006 August 3

ABSTRACT

We present four MIPS (24 μm) and two IRAC (3.6, 4.5, 5.8, and 8.0 μm) *Spitzer Space Telescope* observations of the newly discovered tremendous outburst amplitude dwarf nova (TOAD) Var Her 04 during decline from superoutburst. The four MIPS observations span 271 days, and the two IRAC observations span 211 days. Along the line of sight to Var Her 04, there is a foreground M star within 1″ of the variable; as a result, all of the *Spitzer* photometry presented in this paper is a blend of the foreground M star and Var Her 04. We estimate the quiescent level of the TOAD to be $\Delta V = 4$–5 mag below that of the M star. Based on the spectral energy distribution and the Two Micron All Sky Survey colors, we find the M star to be an M3.5 V dwarf at a distance of 80–130 pc. Based on its outburst amplitude and quiescent apparent magnitude, we estimate the distance to Var Her 04 to be 200–400 pc, suggesting that the line-of-sight foreground star is physically unrelated to the cataclysmic variable. All of the *Spitzer* photometry is consistent with the photospheric emission of the line-of-sight M3.5 V star, except for one 24 μm observation obtained after the variable rebrightened. This 24 μm flux density is 75 μJy (4 σ) above the preceding and following MIPS observations. We tentatively suggest that the mid-infrared brightening of 75 μJy may be associated with a dust formation event in the superoutburst ejecta. Assuming a dust temperature of 100–400 K, we have estimated the amount of dust required. We find that 10^{-13} to 10^{-11} $M_\odot$ of dust is needed, consistent with the amounts of mass ejection in TOADs expected during superoutburst and possibly making TOADs important contributors to the recycling of the interstellar medium.

Key words: circumstellar matter — infrared: stars — novae, cataclysmic variables — stars: individual (Var Her 04)

1. INTRODUCTION

Tremendous outburst amplitude dwarf novae (TOADs) consist of a white dwarf primary star and an extremely low mass main-sequence or brown dwarf secondary star ($M \lesssim 0.1$ $M_\odot$; e.g., Ciardi et al. 1998). With typical orbital periods of a few hours or less, the secondary star is tidally locked to the white dwarf and overfills its Roche lobe. Material from the secondary star is transferred via the inner Lagrange point to an accretion disk surrounding the white dwarf. As material builds in the accretion disk, instabilities in the accretion disk give rise to rare "superoutbursts," which, relative to the preoutburst quiescent luminosity, are 100 times more luminous than outbursts from normal dwarf novae such as U Gem and SS Cyg (e.g., Harrison et al. 2004). These outbursts are not thermonuclear, as is the case for classical novae. Rather, viscous heating causes the disk temperature to rise until ionization of hydrogen occurs, causing a pressure wave to propagate inward, pushing material onto the surface of the white dwarf (Howell et al. 1995a). The release of gravitational energy powers the superoutburst luminosity, with dramatic brightening of 6 mag or more. Superoutbursts for TOADs occur very infrequently, on timescales of multiple decades.

During the superoutburst, TOADs have winds (>5000 km s^{-1}; Howell et al. 1995b) that are strong enough to expel material from the binary system, much like classical novae (Long et al. 2003) and *unlike* other types of dwarf novae that rarely display outflows that exceed (or even approach) escape velocity during outburst (e.g., U Gem and SS Cyg). The outburst declines in TOADs typically last a few hundred days and often show a characteristic 2–3 mag dip in the optical near 50 days (Richter 1992), much like what is seen in the light curves of slow novae near 100 days (e.g., Gehrz et al. 1998; Evans 2001; Evans et al. 2005). In slow novae the optical dip can be 8–10 mag deep and is attributed to the formation of an optically thick dust shell in the ejecta (Smith et al. 1994; Evans 2001; Evans et al. 2005).

In TOADs the optical dip is suggested to be a dramatic drop in the mass transfer rate from the secondary star onto the outbursting accretion disk or a cooling wave propagating through the accretion disk, causing a cessation of the outburst. Approximately 10 days later, the dwarf nova rebrightens (Patterson et al. 2002), attributed to a continuation of the outburst, but at lower luminosity (Richter 1992). However, the evidence for the exact mechanism is sparse.

Given that TOADs have winds strong enough to eject material from the system (like classical novae), an alternative explanation of the optical dip might be the formation of dust within the superoutburst ejecta. The *V*-band (0.55 μm) light curve for the 1995 superoutburst of the TOAD AL Comae has an optical dip

TABLE 1
Dates of *Spitzer* Observations

Observation	UT Date	Days Past Outburst	AOR Key
MIPS-1	2004 Aug 21	67	12000000
MIPS-2	2004 Sep 22	99	12000768
IRAC-1	2004 Oct 7	114	12001024
MIPS-3	2004 Oct 18	125	12001280
IRAC-2	2005 May 6	325	13533696
MIPS-4	2005 May 19	338	13533440

that is 2.5–3 mag deep (Howell et al. 1996), while the corresponding *I*-band (0.9 μm) dip is only 2–2.5 mag deep (Pych & Olech 1995), consistent with the 0.5 mag difference between the dust extinction at 0.55 and 0.9 μm (Mathis 1990). However, no infrared observations to detect the formation of dust during superoutburst have been attempted—until now.

On 2004 June 16 a previously unknown star in Hercules went into outburst (Nakano et al. 2004; Price et al. 2004). Photometric observations revealed the presence of superhumps, which indicated that this was a superoutburst and also provided a means to estimate the orbital period ($P = 81.8$ minutes). Given the large outburst amplitude and the very short orbital period, Var Her 04 was identified as a TOAD. For a given TOAD, superoutbursts are rare (timescales of decades); we took advantage of this timely opportunity to observe the outburst with the *Spitzer Space Telescope*. We obtained two observations with IRAC (3.6, 4.5, 5.8, and 8.0 μm) and four observations with MIPS (24 μm) to investigate whether dust is formed in the ejecta of TOAD superoutbursts and, hence, possibly explain the observed dip in the optical light curves of TOADs whose origin is a mystery.

2. *SPITZER* OBSERVATIONS

Four observations were obtained with the 24 μm channel on the MIPS instrument (Rieke et al. 2004), and two observations were obtained with all four channels (3.6, 4.5, 5.8, and 8.0 μm) of the IRAC instrument (Fazio et al. 2004). The first three MIPS observations (hereafter referred to as MIPS-1, MIPS-2, and MIPS-3) were each separated by approximately 30 days beginning on 2004 August 21, 67 days after the peak of the outburst. The final MIPS observation (MIPS-4) was obtained in 2005 May, almost a full year past the outburst peak. The first IRAC observation (IRAC-1) was obtained between the second and third MIPS observation, and the second IRAC observation (IRAC-2) was obtained near the time of MIPS-4. Table 1 details the dates and number of days past outburst peak for each of the *Spitzer* observations.

The operational mode of the *Spitzer* spacecraft is to observe in advance-scheduled instrument campaigns; i.e., a single instrument for a dedicated period of time. As a result, while our requests of monthly spacing between the observations were generally met, we had no control over exactly when those observations were made. Figure 1 displays a validated *V*-band light curve obtained from the American Association of Variable Star Observers (AAVSO). The times of the MIPS and IRAC observations are marked to indicate when in the outburst the observations were made. As discussed in § 3.1, along the line of sight to Var Her 04 there is an M star within 1″ of the variable. None of the photometric measurements presented in this paper (including the AAVSO light curve) spatially resolve the foreground M star from Var Her 04.

After decline from the primary outburst, there are two minor rebrightening ($\Delta V \approx 0.5$ mag) events peaking at $t = 85$ and

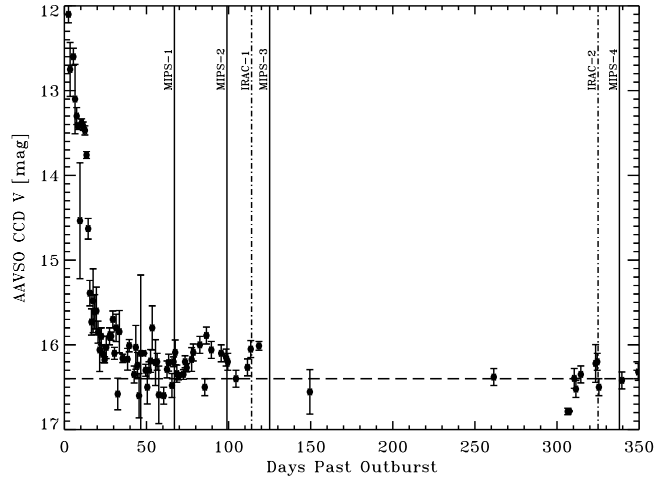

Fig. 1.—CCD visual-magnitude light curve for Var Her 04. Data are from the AAVSO and contain only CCD+*V* validated observations. Data have been rebinned in 1 day wide bins. Error bars represent the dispersion of the observations within that bin. The mean quiescent magnitude of $V = 16.5$ mag, as determined from the points at $t > 250$ days, is marked by the dashed line. This is *not* the quiescent level of the outbursting Var Her 04 but is the visual magnitude of the unrelated line-of-sight foreground M star. The times of the four MIPS and two IRAC observations are marked by the vertical lines.

$t \approx 120$ days (Fig. 1). The full amplitude of these two rebrightenings is uncertain, as the photometry is dominated by the M star when Var Her 04 is faint. The MIPS-1 observation ($t = 67$ days) was made just prior to the first rebrightening. The MIPS-2 observation ($t = 99$ days) was obtained during decline from the first rebrightening. The IRAC-1 observation ($t = 114$ days) was made 30 days after the peak of the rebrightening event ($t = 85$ days) and just prior to the peak of a second rebrightening event ($t \approx 120$ days). The MIPS-3 observation ($t = 125$ days) was obtained just after the second rebrightening event. There are no AAVSO-validated CCD+*V* data corresponding to the time of MIPS-3, but interpolation suggests that the light curve may have been on a slow decline between $t = 125$ and $t = 150$ days. The final *Spitzer* observations (IRAC-2 and MIPS-4) were obtained well after the outburst event had ended and represent the photometric levels of the foreground M star (see § 3.1 below).

The IRAC data were processed with the S13.2.0 pipelines. The MIPS-1, MIPS-2, and MIPS-3 data were processed with the S10.5.0 pipelines, and the MIPS-4 data were processed with the S12.0.2 pipeline. The basic calibrated data for each astronomical observation request (AOR) were subsequently mosaicked using MOPEX (Makovoz & Marleau 2005) to create one single deep image for each of the IRAC and MIPS visits. The total on-source integration time was 570 s for each IRAC observation, consisting of 19 dithered 30 s frames. During each MIPS 24 μm observation, Var Her 04 was observed for a total of 3000 s, consisting of 20 photometry cycles with an exposure time of 10 s per frame. Source identification and aperture photometry was performed using an IDL version of DAOPHOT. Because the MIPS-4 observation was reduced with a slightly different pipeline sequence, only differential photometry was performed on all of the MIPS frames to allow for direct comparison between the visits.

Figure 2 displays "cutouts" of the MIPS-1, MIPS-2, and MIPS-3 images centered on Var Her 04.[1] In the figure the arrows

[1] MIPS-4 appears nearly identical to MIPS-1 and MIPS-3 and is not shown.

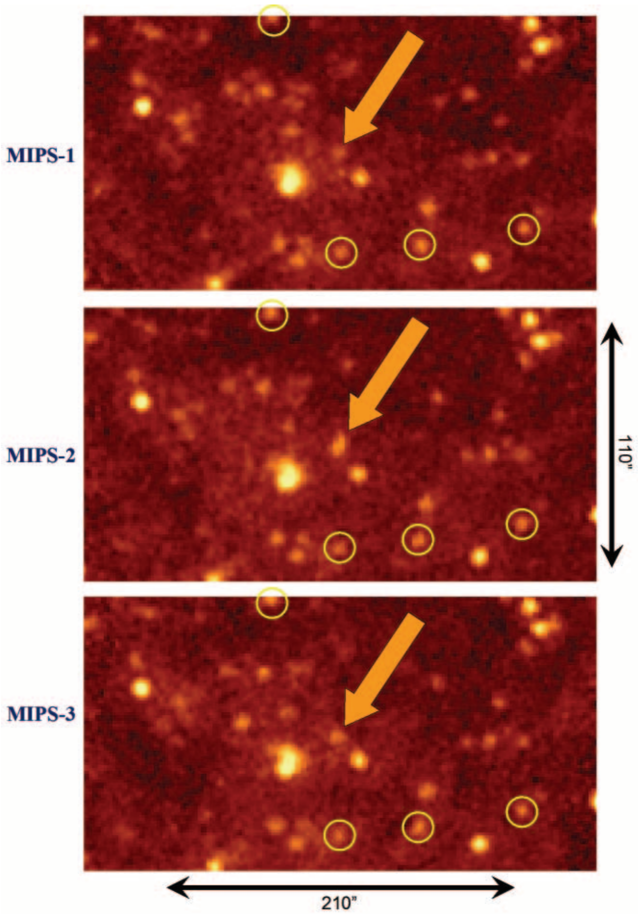

Fig. 2.—The 24 μm cutout images for the MIPS-1, MIPS-2, and MIPS-3 observations. The images, oriented in equatorial coordinates with north up and east to the left, span $210'' \times 110''$ with a pixel scale of $2''.45$ pixel^{-1}. The arrow highlights the position of Var Her 04, emphasizing the appearance of the cataclysmic variable in MIPS-2 and its absence in MIPS-1 and MIPS-3. MIPS-4 (*not shown*) appears identical to MIPS-3. The circled stars are the four stars used for comparison in the ensemble differential photometry.

mark the position of Var Her 04, and the circles indicate the stars used for photometric comparison in the ensemble differential photometry. The equatorial coordinates for each of the comparison stars and the variable are given in Table 2. These comparison stars were chosen because they were within a few arcminutes of Var Her 04, of comparable brightness to Var Her 04 at 24 μm, and apparently photometrically stable at 24 μm. The comparison stars were weighted and combined into an ensemble comparison star (e.g., Everett et al. 2002) and used to perform standard differential photometry on Var Her 04.

3. DISCUSSION

3.1. *Distance to Var Her 04 and the Foreground Star*

Var Her 04, a superoutbursting TOAD, has an orbital period ($P = 81.8$ minutes) and a mass ratio ($q = 0.072$) very similar to that of WZ Sge (Price et al. 2004). During its 2001 outburst, WZ Sge had a peak outburst magnitude near $V = 8$ mag (Patterson et al. 2002), while Var Her 04 had a peak outburst magnitude of $V = 12$ mag (see Fig. 1). TOADs have an average outburst amplitude of $\Delta V \approx 7.5 \pm 0.8$ mag (Howell et al. 1995a). If we assume that WZ Sge and Var Her 04 have the same intrinsic outburst amplitude (as most TOADs do; e.g., Howell et al. 1995b), we can scale the properties of WZ Sge ($d = 43.5 \pm 0.3$ pc; Harrison et al. 2004) to Var Her 04. At $\sim$20–40 times fainter, the implied distance of Var Her 04 is $\sim$4.5–9.0 times farther away than WZ Sge, for an estimated distance of $d \approx 200$–400 pc.

TABLE 2

Coordinates

Star	R.A. (J2000.0)	Decl. (J2000.0)
Var Her 04	18 39 26	26 04 08
Comparison 1	18 39 20	26 03 39
Comparison 2	18 39 24	26 03 32
Comparison 3	18 39 26	26 03 29
Comparison 4	18 39 28	26 05 07

Note.—Units of right ascension are hours, minutes, and seconds, and units of declination are degrees, arcminutes, and arcseconds.

There is a foreground star located $\approx 1''$ southeast of Var Her 04. Because of the line-of-sight proximity of the foreground star, all of the photometry presented in this work is an unresolved blend of Var Her 04 and the foreground star. To understand the contribution of the foreground star to our photometry, we retrieved the near-infrared photometry at the position of the foreground star (2MASS J18392619+2604087) from the Two Micron All Sky Survey (2MASS; Skrutskie et al. 2006) archive. The 2MASS star has near-infrared magnitudes of $J = 13.399 \pm 0.036$, $H = 12.853 \pm 0.043$, and $K_s = 12.542 \pm 0.033$ mag. The quiescent near-infrared brightness for the resolved variable Var Her 04 is $J \approx 17$ mag (Price et al. 2004). Thus, while the 2MASS magnitudes are an unresolved blend between the foreground star and Var Her 04, the variable contributes less than 3% to the total near-infrared brightness, and the magnitudes, as measured by 2MASS, are dominated by the foreground star.

We have plotted the 2MASS colors in the JHK_s color-color diagram shown in Figure 3. Because of the divergence of the

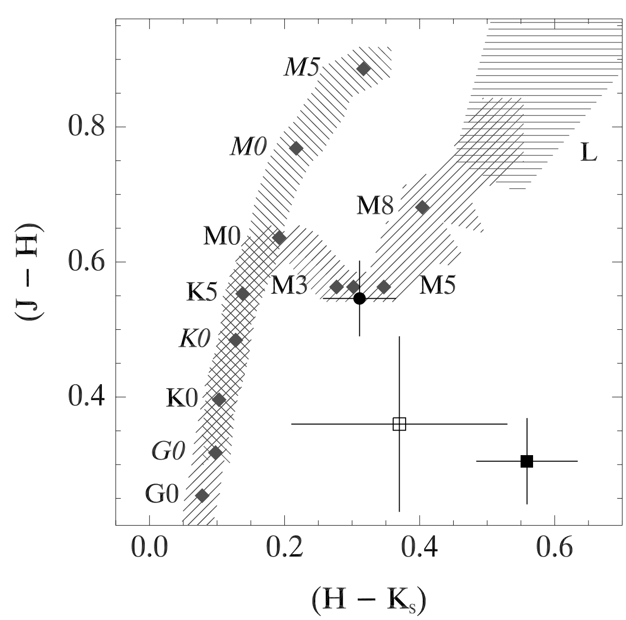

Fig. 3.—2MASS color-color diagram for dwarf and giant stars. The dwarf stars occupy the lower branch and separate from the giant stars at a spectral type of M0. The 2MASS color photometry of the foreground star is marked by the circle. The 2MASS color of the TOAD WZ Sge (in quiescence) is marked by the filled square. The position of Var Her 04 (in quiescence) is also marked (*open square*), showing that it has similar colors to WZ Sge. Note that the *JHK* photometry for the quiescent Var Her 04 is from Price et al. (2004) and is not in the native 2MASS magnitudes. Diamonds mark the fiducial spectral types.

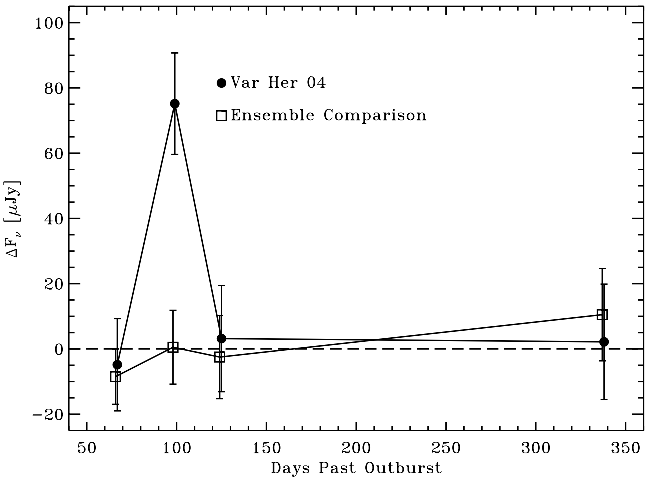

FIG. 4.—Differential 24 μm photometry from the MIPS observations. The mean of the ensemble stars has been set to zero, as marked by the dashed line. For the cataclysmic variable, the mean level of the 24 μm flux densities (for MIPS-1, MIPS-3, and MIPS-4) has been set to zero after subtraction of the ensemble flux densities.

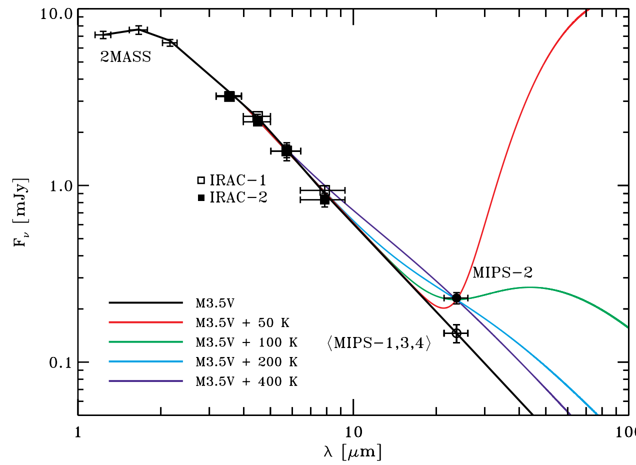

FIG. 5.—Spectral energy distribution for the unresolved photometry of the cataclysmic variable and the line-of-sight foreground M dwarf. An M3.5 V dwarf template, scaled to the 2MASS *J*-band photometric point, is shown in black. The "high-state" MIPS-2 data point is also shown, with four different blackbody curves forced to fit the MIPS-2 data point.

near-infrared colors of giants and main-sequence stars for spectral types later than about K5, the 2MASS photometry allows us to identify unambiguously the foreground star as a main-sequence object with spectral type M4$\pm$0.5. The near-infrared colors for the short orbital period dwarf nova WZ Sge could not be mistaken for those of a normal, low-mass, main-sequence star (see Fig. 3). The near-infrared colors of WZ Sge are quite similar to those reported by Price et al. (2004) for the resolved quiescent variable (Fig. 3).

Comparing the 2MASS *J*-band magnitude of the foreground star with the absolute magnitudes expected for M3–M4 dwarf stars ($M_J \approx 7.8$–8.9; Hawley et al. 2002), we find a distance range of $d \approx 80$–130 pc for the foreground star, which is substantially closer than Var Her 04 and suggests that the foreground star is merely along the line of sight and physically unrelated to Var Her 04.

Scaling the quiescent brightness of WZ Sge ($V = 15.5$ mag; Patterson et al. 2002), Var Her 04 has an expected quiescent brightness of $V \approx 19.5$ mag, suggesting that the $V = 16.5$ mag floor in Figure 1 (*dashed line*) is *not* the quiescent level of Var Her 04 but rather the visual magnitude of the foreground M star.

With an expected quiescent value of $V \approx 19.5$ mag and an outburst amplitude of $\Delta V \approx 7.5$ mag, Var Her 04 is similar in brightness to the TOAD AL Comae ($V \approx 20$ mag, $\Delta V \approx 8$ mag; Howell et al. 1996). AL Com is at a distance of $\approx$250 pc (Sproats et al. 1996), consistent with the distance estimated for Var Her 04 from the peak outburst brightness.

3.2. *Mid-Infrared Photometry*

The differential light curve for the four MIPS observations (Fig. 4) clearly shows that at the time of MIPS-2 ($t = 99$ days), Var Her 04 is 75 μJy brighter than it is at the time of MIPS-1, MIPS-3, and MIPS-4. The ensemble comparison does not exhibit the same brightness change and remains within 1 σ of the "zero level." The MIPS-2 photometric point is $\sim$4 σ away from the zero-level baseline. The brightness level increase in MIPS-2 can be seen by eye in Figure 2. MIPS-4 was obtained $t = 338$ days after the outburst event and sets the baseline for the M star flux density at 24 μm. The agreement of MIPS-1 and MIPS-3 with MIPS-4 implies that the two former observations are primarily of the foreground M star without a significant contribution from Var Her 04. Only the 24 μm flux density at MIPS-2 is significantly different.

For the two IRAC observations, absolute aperture photometry was performed. The ensemble comparison stars were used to check for changes between the IRAC-1 and IRAC-2 observations, but no significant deviations were detected. As IRAC-2 was obtained long after the outburst event had ended, the agreement between the IRAC-1 and IRAC-2 photometry, separated by over 200 days (see Fig. 1), indicates that both IRAC-1 and IRAC-2 are dominated by the foreground M dwarf and contain little (if any) contribution from Var Her 04.

We scaled an empirical template for the 2MASS and IRAC flux densities of an M3.5 V star (Patten et al. 2006) to the 2MASS *J*-band flux density (Fig. 5). The resulting reduced χ^2 of the M3.5 V template fit to the 2MASS-IRAC data is $\chi^2_\nu \approx 1$. The M3 V and M4 V templates were also fitted but resulted in significantly worse χ^2 values ($\chi^2_\nu \gtrsim 10$). The goodness of the M3.5 V fit for both the 2MASS and the IRAC data indicates that the IRAC data (like the 2MASS) are dominated by the M3.5 V star, with little contribution from Var Her 04.

The MIPS 24 μm differential photometric data (Fig. 4) were scaled such that the weighted mean of the MIPS-1, MIPS-3, and MIPS-4 data equaled the M3.5 V template extrapolated to 24 μm. All of the photometry from the four MIPS campaigns and the two IRAC campaigns are reported in Table 3. In the following section, we discuss the source of the 24 μm brightening seen in MIPS-2.

3.3. *The* 24 μm *Brightening*

Using Figure 1 as a reference, the optical (V) emission begins to rise again just after the MIPS-1 observation ($t = 67$ days) and after the initial decline from the primary outburst. The cause of this rebrightening is unknown but may be a continuation of the outburst event. At $t = 85$ days the V emission peaks and begins to decline again with a minimum near $t = 105$ days. The MIPS-2 observation at $t = 99$ days is nearly at this minimum.

The MIPS-3 observation ($t = 125$ days) was obtained on a day with no validated AAVSO CCD+V data. However, if we assume that the decline rate in V from $t = 115$ to $t = 125$ days equals the climb rate in V from $t = 105$ to $t = 115$ days, then the V magnitude at the time of MIPS-3 equals the V magnitude at the

TABLE 3
Flux Densities

Bandpass (μm)	Flux Density (mJy)	Observation ID
1.235 (0.162)................................	7.12 ± 0.34	2MASS J
1.662 (0.251)................................	7.59 ± 0.42	2MASS H
2.159 (0.262)................................	6.42 ± 0.28	2MASS K_s
3.550 (0.75)..................................	3.19 ± 0.07	IRAC-1
	3.22 ± 0.10	IRAC-2
4.493 (1.015)................................	2.46 ± 0.06	IRAC-1
	2.29 ± 0.09	IRAC-2
5.731 (1.425)................................	1.57 ± 0.13	IRAC-1
	1.56 ± 0.18	IRAC-2
7.872 (2.905)................................	0.94 ± 0.06	IRAC-1
	0.83 ± 0.08	IRAC-2
23.7 (4.7)......................................	0.15 ± 0.02	⟨MIPS-1, 3, 4⟩[a]
	0.23 ± 0.02	MIPS-2

Note.—Unresolved photometry of Var Her 04 and foreground line-of-sight M star.
[a] Mean of differential photometry from MIPS-1, MIPS-3, and MIPS-4 scaled to the M3.5 V template.

time of MIPS-2. In fact, we expect the V-band decline rate to be *slower* than the V-band climb rate (e.g., AL Com; Howell et al. 1996). Thus, the V-band brightness at the time of MIPS-3 is likely *brighter* than the V-band brightness at the time of MIPS-2. We note here that the true rates of rise and decline and the true depths of the minima are diluted by the presence of the unresolved foreground M star.

The 24 μm emission associated with MIPS-3 is less than the 24 μm emission at MIPS-2, even though the V magnitude at the time of MIPS-3 is (likely) brighter than or equal to the V magnitude at the time of MIPS-2. Furthermore, the 24 μm emission at MIPS-3 equals the 24 μm emission associated with MIPS-1 and MIPS-4, suggesting that the 24 μm emission observed at MIPS-1, MIPS-3, and MIPS-4 is dominated by the foreground M star. Thus, the 24 μm increase observed at $t = 99$ days (MIPS-2) occurs *not* because Var Her 04 simply has gotten brighter, but rather because there is an additional emission source associated with Var Her 04.

It is conceivable that the foreground M star could have undergone a flare event exactly at the time of the MIPS-2 observation. However, as flare events generally last a few hours or less (e.g., Rockenfeller et al. 2006), the MIPS-2 visit would have to coincide exactly with the flare. In addition, we inspected the first and second halves of the MIPS-2 data cube to search for variability within the MIPS-2 observation, as might be expected if the M star had undergone a flare event. We found the photometry of Var Her 04 for the split data to agree within 1–2 μJy, indicating that there is no significant change in brightness during the MIPS-2 observation. Consequently, we attribute the 24 μm brightening solely to the variable Var Her 04.

We hypothesize that Var Her 04 may have undergone a dust formation event (near $t = 85$ days) during the optical rebrightening event in a manner very similar to what occurs in slow-nova dust formation events (e.g., Evans et al. 2005). After a steady decline since peak outburst, Var Her 04 begins to rebrighten ($t = 65$ days). Although the exact rate and level of the decline and full rebrightening is lost in the confusion of the foreground star, typical rebrightening in TOADs is $\Delta V \approx 2-3$ mag (e.g., WZ Sge and AL Com; Richter 1992; Kuulkers et al. 1996).

In our hypothesis the rebrightening event at $t = 65$ days may be sufficient to allow dust production to occur (at $t = 85$ days), and the amount of dust produced is sufficient to obscure the optical emission from Var Her 04, causing the V magnitude to drop. At $t = 105$ days the dust is at its densest and the optical emission is at a minimum. The exact level of this dip is lost in the glare of the foreground M star. It is at this conjuncture that the infrared emission from the dust is at its peak brightness (MIPS-2).

The dust shell continues to expand. As the dust dissipates, the optical emission from Var Her 04 is unveiled and the V-band light curve rebrightens. As the dust dissipates, the 24 μm emission declines (MIPS-3) and returns to the preevent level (MIPS-1), which also equals the final quiescent level (MIPS-4). If this proposed scenario is correct, the dust forms and dissipates in approximately $\Delta t = 50$ days ($t \approx 70-120$ days).

Without a contemporaneous flux density at a longer wavelength (e.g., 70 μm), we cannot constrain the dust temperature T_d. We can assume, however, a reasonable set of dust temperatures (50, 100, 200, and 400 K). In Figure 5 we display the composite spectral energy distribution with the 50, 100, 200, and 400 K blackbody curves overlaid (recall that the 2MASS and *Spitzer* photometry does not spatially resolve the foreground star from Var Her 04). The 50, 100, 200, and 400 K blackbody curves predict 70 μm flux densities in outburst of 10, 0.2, 0.03, and 0.02 mJy, respectively.

Without a 70 μm (or longer) flux density, we cannot differentiate between dust temperatures, but we can estimate the amount of dust required to produce the 75 μJy brightening at 24 μm for each of these dust temperatures via

$$M_d = \frac{(16/3)\pi a \rho D^2}{Q_\nu B_\nu(T_d)} F_\nu, \tag{1}$$

where F_ν is the observed flux density at frequency ν, Q_ν is the grain emissivity at frequency ν, a is the grain radius, ρ is the grain mass density, D is the distance to Var Her 04, and B_ν is the Planck function at dust temperature T_d. Assuming $a = 0.5$ μm, $\rho = 1$ g cm^{-3}, $Q_\nu = 0.1(\lambda/\mu\mathrm{m})^{-\alpha}$, and $\alpha = 0.45$ (e.g., Muthumariappan et al. 2006), we estimate dust masses of 10^{-8}, 10^{-11}, 10^{-12}, and 10^{-13} $M_\odot$ for dust temperatures of 50, 100, 200, and 400 K, respectively.

For an outburst amplitude of $\Delta V = 7.5$ mag, a typical TOAD accretes approximately 10^{-10} to 10^{-9} $M_\odot$ onto the white dwarf surface during a superoutburst (Osaki 1996; Cannizzo 2001). For a rebrightening event of $\Delta V = 2$–3 mag, the expected amount of material ejected just from this event may be 50–100 times less. Even if all of this material is ejected from the white dwarf surface *and* all of that material forms dust, there is not enough mass to explain the 24 μm emission if the dust temperature is less than $\sim$100 K. However, if a few percent of this material is ejected from the white dwarf surface and condenses into dust grains outside the sublimation radius, the derived dust masses for dust temperatures of 100–400 K are consistent with the anticipated accretion amounts during a superoutburst event.

Theory predicts that there are 10^4–10^5 TOADs throughout the Galaxy (e.g., Howell et al. 2001). If each TOAD outbursts, on average, once every 10 yr, then there may be 10^3–10^4 outbursts per year throughout the Galaxy. If each outburst produces 10^{-13} to 10^{-11} $M_\odot$ of dust, this corresponds to 10^{-10} to 10^{-8} $M_\odot$ of dust injected into the interstellar medium per year. On average, there is one classical nova per year in the Galaxy, and each classical nova ejects 10^{-9} to 10^{-6} $M_\odot$ of dust into the interstellar medium (Gehrz et al. 1998), perhaps making the total population of TOADs as important as classical novae in the recycling of the interstellar medium.

4. SUMMARY

We have obtained *Spitzer* MIPS and IRAC observations of the newly discovered tremendous outburst amplitude dwarf nova (TOAD) Var Her 04 in decline from superoutburst. Four MIPS observations at 24 μm were made spanning 271 days. In addition, two sets of IRAC observations (all four bands) spanning 211 days were also made. All of the *Spitzer* photometry is consistent with the photospheric emission of a line-of-sight (but physically unrelated) M3.5 V star, except for one 24 μm observation obtained after the variable rebrightened. We tentatively suggest that the mid-infrared brightening of 75 μJy may be associated with a dust formation event. We estimate that the amount of dust required to produce such a brightening at 24 μm is only 10^{-13} to 10^{-11} $M_{\odot}$, consistent with the amount of material expected in superoutburst ejecta. Given the total population of TOADs in the Galaxy, TOADs may be as important as classical novae in terms of their production of dust. A dedicated observing program to study TOADs (that are not spatially confused with foreground stars) in superoutburst is needed to more clearly understand the ejecta processes and the contribution of TOADs to the recycling of the interstellar medium.

The authors would like to thank the Director of the *Spitzer* Science Center for granting our observing request through the Director's Discretionary Time. This work has been supported, in part, by NASA through the *Spitzer* Science Center and the Michelson Science Center at Caltech. We also extend a special thank you to Steve Schurr for his enthusiasm and red pen.

We acknowledge with thanks the variable star observations from the AAVSO International Database contributed by observers worldwide and used in this research. This research has made use of the NASA/IPAC Infrared Science Archive, which is operated by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration. This publication makes use of data products from the Two Micron All Sky Survey, which is a joint project of the University of Massachusetts and the Infrared Processing and Analysis Center, California Institute of Technology, funded by the National Aeronautics and Space Administration and the National Science Foundation.

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